NASA/CR-97- 206143

Final Report: NAG5-1906

Studies of Error Sources in Geodetic VLBI

by A.E.E. Rogers, A.E. Niell, and B.E. Corey

Achieving the goal of millimeter uncertainty in three dimensional geodetic positioning on a global scale requires significant improvement in the precision and accuracy of both random and systematic error sources. For this investigation we proposed to study errors due to instrumentation in VLBI and due to the atmosphere. After the inception of this work we expanded the scope to include assessment of error sources in GPS measurements, especially as they affect the vertical component of site position and the measurement of water vapor in the atmosphere. The atmosphere correction improvements described below are of benefit to both GPS and VLBI.

Accomplishments:

<u>Atmosphere</u>

1) New hydrostatic and wet mapping functions (designated NMF) which are parameterized by day-of-year, height above sea level, and latitude were developed (Niell, 1996). Tested against a global radiosonde data set, they have the smallest biases of existing mapping functions, yet have comparable precision. Since they are independent of surface meteorology, they are well suited for GPS as well as VLBI applications and are now included in most major analysis packages for both VLBI and GPS.
2) A top-down model for a hydrostatic mapping function that is parameterized directly in terms of both surface meteorology and troposphere conditions, including a seasonal model for the height of the tropopause (Rogers and Niell, 1995a) was derived. It is based on ray tracing of the Standard Atmospheres. It has not been tested against actual radiosonde data.
3) A hydrostatic mapping function based on the thickness of the atmosphere, obtained as the geopotential height of an isobaric surface, was developed. Based on comparison with a global distribution of radiosonde data, this should reduce the error in geodetic positions and in the estimate of the delay by the atmosphere due to the hydrostatic mapping function by a factor of about two (Niell and Machacek, 1996).
3) Gradients in refractivity in the atmosphere at low elevations, which were measured with the Haystack antenna at 22 GHz, are most likely due to horizontal gradients in water vapor or temperature, but are not likely to be due to differences in the vertical distributions or to a gradient in pressure (Rogers and Niell, 1995b). Such gradients in water vapor are also observed in direct measurements with a microwave water vapor radiometer (Davis et al, 1993).
4) A two-week campaign (called WAVE) to measure the distribution of water vapor within 25 km of the Westford geodetic VLBI antenna and the collocated Cignet/IGS GPS antenna was conducted in 1995 August. Eleven GPS systems and a water vapor radiometer were operated continuously during and around the CONT95 geodetic VLBI session. In addition radiosondes were flown twice per day. These data are being analyzed for instrumental GPS errors as well

as for the determination of atmospheric water vapor. The primary results (to be submitted to Journal of Atmospheric and Oceanic Technology) are:

a) The same GPS antenna type (Dorne-Margolin with choke ring), when placed in different electromagnetic environments, has different elevation dependent phase characteristics which renders the estimated position and atmosphere delays sensitive to the minimum elevation of included data. Errors of several centimeters of height and of zenith wet delay result.

b) We confirm significant differences in the measurement of relative humidity by Vaïsala radiosondes and by VIZ radiosondes as analyzed by the NWS. This leads to uncertainty in the calibration of WVRs because of their dependence on radiosondes for determination of the retrieval coefficients.

c) VLBI may provide the best accuracy among the four methods (WVR, radiosonde, GPS and VLBI) of measuring wet delay in the atmosphere.

Instrumentation:

VLBI:

We have studied the dynamic range of the S/X geodetic receivers and the MkIII VLBI terminals and found that they are not limiting the accuracy of the VLBI results, provided the strength of the phase calibration signal is kept below a prescribed level. Methods for detecting spurious signals at the stations and for reducing them to acceptable levels have been developed. In the absence of significant spurious signals, phase ripple has been found to be stable for periods longer than the 24 hours of typical experiments for all stations studied, and corrections are routinely introduced for the high-accuracy R&D and VLBA observations. The level of repeatability of delay estimates from a MkIII correlator has been studied to determine the minimum contribution to noise in the geodetic VLBI results.

GPS:

1) The error in the vertical component of site position due to scattering near the antenna was measured for the FLINN monument at the Haystack Observatory. A possible solution was tested and shown to reduce the effect significantly (Elósegui et al, 1995).
2) Estimates of the vertical site position and of precipitable water vapor were shown to depend on the type of monument in the WAVE observations (Niell et al, 1995).
3) Data were taken to determine the effect of the Ashtech-designed radome on measurements with choke-ring antenna. The radome causes an elevation-dependent phase error that results in a height error of several centimeters. The AOA and Ashtech choke-ring antennas were also compared in these tests and found to give the same geodetic results to within approximately 1 mm (Niell, King, McCluskey, and Herring 1996).
4) Based on the studies under this grant the development of a GPS calibration system to measure the effect of *in situ* phase center errors in GPS antenna/mount combinations was proposed, and the effort has been funded by the NSF (J.L. Davis (P.I.), B.E. Corey, A.E. Niell, A.E.E. Rogers, T.A. Clark, et al).

REFERENCES

Davis, J.L., G. Elgered, A.E. Niell, and C.E. Kuehn, Ground-based measurement of gradients in the 'wet' radio refractivity of air, *Radio Science*, *28*, 1003-1018, 1993.

Elósegui, P., Davis, J.L., Jaldehag, R.T.K., Johansson, J.M., Niell, A.E., Shapiro, I.I., "Geodesy Using the Global Positioning System: The Effects of Signal Scattering on Estimates of Site Position", JGR, Vol.100, No.B7, 9921-9934, June 10, 1995.

Niell, A.E., "Global mapping functions for the atmosphere delay at radio wavelengths", JGR - Solid Earth, .JGR, Vol.101, No.B2, 3227-3246, February 1996

Niell, A.E, and M. Machacek, "Improving the accuracy of the hydrostatic mapping function", Proceedings of the Technical Workshop for APT and APSG (TWAA96), Kashima, Japan, December 1996.

Niell, A.E., R.W. King, S.C. McClusky, and T.A. Herring, "The Effect of Radomes on Dorne-Margolin Choke Ring GPS Antennas", AGU 1996 May (INVITED).

Niell, A..E., A.J. Coster, F. Solheim, V. Mendes, P. Toor, and R. Langley, "Comparison of the Measurements of Water Vapor by GPS, VLBI, WVR, and Radiosondes during CONT95", EOS, Vol.76, p.F145, 1995.

Rogers, A.E.E., and A.E. Niell, "A top down model of the dry path delay through the atmosphere", VLBI Geodetic Technical Memo No.10, Haystack Observatory, 1995a.

Rogers, A.E.E., and A.E. Niell, "Atmospheric refraction and horizontal refractivity gradients", VLBI Geodetic Technical Memo No.9, Haystack Observatory, August 30, 1995.